NUCLEAR ENERGY INSTITUTE

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November 8, 2000

Dr. Brian W. Sheron
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Office of Nuclear Reactor Regulation
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Mail Stop O5-E7
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REFERENCE: NEI (D. J. Modeen) letter to NRC (B. W. Sheron), dated October 6, 2000, *Insights and Implications of Steam Generator Operating, Inspecting and Maintenance Experience*

SUBJECT: Interim Guidance for In Situ Pressure Testing

PROJECT NUMBER: 689

Dear Dr. Sheron:

As explained in the referenced letter, the steam generator tube failure event at Indian Point Unit 2 and the issues surrounding the in situ pressure testing of selected tubes and test specimens at Arkansas Nuclear One Unit 2, prompted industry to evaluate its steam generator program guidance. The referenced letter forwarded the industry lessons learned from these occurrences. The purpose of this letter is to share with the NRC staff the industry's interim guidance for in situ pressure testing established subsequent to our earlier letter.

The NEI Steam Generator Program Task Force and EPRI SGMP Issues Integration Group have had interactions with the ANO Unit 2 staff regarding the application of the EPRI Tube Integrity Assessment and In-situ Pressure Testing Guidelines. This contact confirmed the robust and helpful nature of the current industry guidance, yet also identified the need for further action. As a result, the EPRI SGMP initiated a study of the ANO steam generator tube pressure testing results. The purpose of the study is to:

- Perform a careful analysis of the data to verify the phenomenon

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- Provide an initial explanation of the results

- Assess whether there was any effect of pressurization rate on currently existing tube burst databases utilized by industry for tube integrity assessment

- Evaluate the implications of this data on future in situ testing and integrity assessment of stem generator tubes

The NEI Steam Generator Program Task Force has met with the NRC staff on three separate occasions to provide a status of the study and to present preliminary results. Although the study is not yet complete, enough information has been obtained to allow the publication of interim guidance on in situ pressure testing to the industry. The SGMP letter that forwarded this guidance is enclosed. The NEI Task Force expects to continue updating the staff on the study findings as it proceeds towards completion.

We hope you find this information useful and would be pleased to discuss any of these topics in more detail at your convenience.

Sincerely,

David J. Modeen

JHR/maa
Enclosure

c: Mr. Joseph L. Birmingham, U.S. Nuclear Regulatory Commission
Mr. Scott F. Newberry, U.S. Nuclear Regulatory Commission
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October 13, 2000

To: Steam Generator Management Program Utility Steering Committees
PMMP Steering Committee
Senior Representatives
Technical Advisory Group (TAG)

From: Lawrence F. Womack
Chairman, Steam Generator Management Program

Subject: Steam Generator Management Program (SGMP) Interim Guidelines on In Situ Pressure Testing of Steam Generator Tubes

References:

1. Letter, Lawrence F. Womack to Steam Generator Management Program (SGMP) Utility Steering Committees, "Information Letter Concerning Lessons Learned from a Review of Recent Steam Generator Related Issues," September 29, 2000
2. EPRI Final Report, TR-107620-R1, *Steam Generator In Situ Pressure Test Guidelines*, June 1999
3. EPRI Final Report, NP-6865-L, Volumes 1 and 2, *PWR Steam Generator Tube Burst Results (Framatome Data)*, April 1990
4. Draft EPRI Final Report, *Steam Generator Tubing Flaw Handbook*, August 2000, Unpublished
5. NRC Contractor Report, *Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes*, NUREG/CR-6664, ANL-99/23, August 2000

Summary

Recently, the EPRI SGMP reviewed recent industry events and disseminated to the industry timely information with regard to steam generator inspection, condition monitoring, and operational assessment (see Reference 1). Reference 1 indicated that guidance on certain issues would be provided as it is developed and approved. This letter communicates interim additional guidance relative to that specified in Reference 2. In some areas, the interim guidance modifies information contained in Reference 2. Due to the important nature of this issue, it is recommended that this interim guidance be implemented as soon as possible.

It was noted in Reference 1 that recently obtained test data suggested that the burst pressure of a degraded tube could depend on the pressurization rate and that interim guidance would be forthcoming for use in field pressure testing of steam generator tubes. An evaluation of these April 1990 data has been performed and a theoretical understanding of the phenomena has been achieved. Based on this understanding, it is concluded that changes to Reference 2 are required. Interim guidance, in conjunction with applicable information contained in Reference 2, for in situ pressure testing of steam generator tubes is as follows.

- Test all indications above screening criteria presented in Reference 2 – not just the worst five indications as currently stipulated in Reference 2. (Note: Screening criteria must account for all input uncertainties. See NEI Review Board Decision, TUBE-2, In Situ Screening Criteria.)
- A minimum hold time of two minutes is required to verify crack stability at conditions of normal operating, limiting accident (e.g., main steam line break condition), and $3\Delta P_{normal}$ differential pressure, regardless of pressurization rate.
- Intermediate hold pressures with the minimum two-minute hold times at approximately every 500 psig or less, above the limiting accident differential pressure, should be used to approach the proof pressure required to meet the performance criteria. Select the intermediate pressures commensurate with the desired accuracy of the final pressure.
- Pressurization rates should be maintained less than 200 psi/sec, as averaged over the time interval to each hold point.
- If leakage develops, insert a sealing bladder prior to raising pressure, if possible, but not before demonstrating leakage integrity at the limiting accident (e.g., main steam line break) condition.
- For cases where screening criteria applied to axial indications indicate a need for leak testing but not pressure proof testing, one should still perform a pressure proof test.

The first five of the above six bullets apply to in situ pressure testing of steam generator tubes exhibiting any defect morphology. The last bullet is specified to account for possible time-dependent deformation and tearing of small ligaments as explained later in this letter. This bullet does not apply for axial indications restricted from burst (IRB) as defined in Appendix E of Reference 2.

Introduction

The EPRI SGMP has developed interim guidance associated with Reference 1 that is presented in this letter for your immediate use. This guidance is necessary because of unexpected results obtained during leak and burst testing of deep with varying depth, planar, axial EDM slots of 1.4 inches in length performed for ANO 2, in which the failure pressure showed a dependence on the pressurization rate.

The unexpected test results relate to any crack, greater than the through-wall critical crack length, that contains crack segments greater than 90% through-wall. However, the absence of the rate effect at very slow rates of pressurization has not been specifically demonstrated for other defect morphologies. Thus, the interim guidance applies to all morphologies.

This guidance, along with supporting and explanatory information and identification of affected sections in Reference 2, are presented in this letter. Additionally, industry feedback to the SGMP concerning plant implementation of this guidance is requested via this letter.

Discussion

A series of burst and leak tests on tubes with defects simulated by EDM slits were performed by a contractor (Westinghouse) for ANO 2 to elucidate results from an in situ test performed on a degraded steam generator tube at ANO 2. The purpose of the tests was to demonstrate that the degraded steam generator tube would have exhibited a higher burst pressure if a bladder had been used in the in situ test. The initial results of these tests, reported to the NRC on June 8, 2000, suggested that the burst pressure depended on the pressurization history, which includes the pressurization rate and any hold time at a given pressure. To further examine this unexpected phenomenon, Westinghouse and E-Mech were contracted by EPRI for the SGMP to perform a careful analysis of these data to verify the phenomenon, provide, if possible, an initial explanation for the phenomenon, and assess whether there was any effect of pressurization rate on currently existing tube burst databases utilized by industry for tube integrity assessment. The implications of these data on future in situ testing and integrity assessment of steam generator tubes were also evaluated. The results of this examination are documented in a draft EPRI final report titled "Steam Generator Tubing Burst Test Review," which is expected to be published in 2001. To provide explanatory information in support of the guidance presented in this letter, pertinent material is extracted or summarized from this report and provided below.

A review of the ANO 2 EDM pressure test results intended to simulate the structural integrity of tube R72C72 resulted in the following pertinent points.

- The samples tested without a bladder or foil reinforcement and pressurized at a "slow" rate (i.e., pressurization to failure occurred over a 10 to 240 min. duration) failed at a statistically significant lower pressure than the samples tested with a bladder and foil reinforcement pressurized at a "fast rate" (i.e., pressurization to failure occurred in two seconds, ~2000 psig/sec).
- The mean slow rate failure pressure was about 25% less than the mean fast rate failure pressure. This rate effect has not been observed previously in over 25 years of steam generator tube testing.
- The failure (i.e., high leakage) at the slow rate occurred at a pressure predicted by the Cochet correlation (References 3, 4) for ligament tearing, which is in agreement with standard industry methods.
- The increased burst pressures obtained at the fast pressurization rates are not currently predicted by analysis.
- The rate effect is due to the morphology of the specimen and not to material property changes resulting from high pressurization rates (see next bullet) or bladder reinforcement.
- Tensile tests confirmed that increasing the strain rate by 25% only increased the flow stress by 2%. Thus, there is not an inherent phenomenon occurring during fast pressurization that causes an increase in tube material strength properties that explains the 25% increased burst pressure.

- It is postulated (subject to further review) that tearing of thin ligaments is ultimately a fracture problem and not a plastic collapse problem. It is further postulated that small ligaments beneath very deep cracks can tear from small amounts of time-dependent deformation. This implies that the small ligaments require a finite amount of time prior to failure at the failure stress. Thus, if rapid pressurization occurs, ligament tearing occurs at some finite time after the failure pressure is reached and results in an apparent high burst pressure.

As noted earlier, the rate effect occurs if deep crack sections are in the vicinity of 90 to 95% through-wall in an irregular planar crack that is longer than the critical length for a 100% TW crack.

With respect to the validity of presently available laboratory burst test data and burst pressure correlations, it is shown that:

- A wide range of pressurization rates has been used with most of the data in the range of 20 psi/sec to 2000 psi/sec, although the current recommendation for burst pressure testing is 200 psi/sec to 2000 psi/sec.
- No dependency on pressurization rate was found in any of the industry standard correlation data sets.
- Inspection of approximately 100 pressure-time curves for in situ pressure tests, with some flaw depths up to 99% through-wall, showed no indications of an increase in leak rates after several minutes of holding at pressures up to $3\Delta P_{normal}$.
- If the failure pressure could be accurately predicted, it is expected that a degraded tube would fail at the same pressure, regardless of the time history of reaching that pressure if a hold period was attempted at the failure pressure. The difficulty is in accurately knowing the failure pressure, so as not to overshoot it during testing and therefore obtaining a false high measurement. Further discussion of this point is provided below.

With regard to the last bullet, a good analogy of the problem with determining tube burst pressure is the analysis of solutions using chemical titration. If the approximate end point is known, the analyst can rapidly add 90% of the required titrant and then slowly approach the end point. If too much titrant is added near the end point, the actual concentration will be overestimated and the best estimate is that the concentration is greater than the amount determined by the last known addition before the color change. Likewise, for in situ pressure testing of morphologies susceptible to rate effects, the best estimate is that the failure pressure is greater than the last known stable hold point. Therefore, how quickly one approaches the predicted failure pressure is determined by how accurately one wants to know the actual burst pressure. If an accuracy of 200 psig is desired, one should hold at each 200 psi increment prior to reaching failure or pressurize slowly to ensure the pressure does not overshoot the failure pressure.

Conclusion

Based on the above information, interim guidance, in conjunction with applicable information contained in Reference 2, for in situ pressure testing of steam generator tubes is presented as follows.

- Test all indications above screening criteria presented in Reference 2 – not just the worst five indications as currently stipulated in Reference 2. (Note: Screening criteria must account for all input uncertainties. See NEI Review Board Decision, TUBE-2, In Situ Screening Criteria.)
- A minimum hold time of two minutes is required to verify crack stability at conditions of normal operating, limiting accident (e.g., main steam line break condition), and $3\Delta P_{normal}$ differential pressure, regardless of pressurization rate.
- Intermediate hold pressures with the minimum two-minute hold times at approximately every 500 psig or less, above the limiting accident differential pressure, should be used to approach the proof pressure required to meet the performance criteria. Select the intermediate pressures commensurate with the desired accuracy of the final pressure.
- Pressurization rates should be maintained less than 200 psi/sec, as averaged over the time interval to each hold point.
- If leakage develops, insert a sealing bladder prior to raising pressure, if possible, but not before demonstrating leakage integrity at the limiting accident (e.g., main steam line break) condition.
- For cases where screening criteria applied to axial indications indicate a need for leak testing but not pressure proof testing, one should still perform a pressure proof test.

The first five of the above six bullets apply to in situ pressure testing of steam generator tubes exhibiting any defect morphology. The last bullet is specified to account for possible time-dependent deformation and tearing of small ligaments as explained in this letter. This bullet does not apply for axial indications restricted from burst (IRB) as defined in Appendix E of Reference 2.

The requisite interim changes to the EPRI In Situ Pressure Test Guidelines to incorporate the above guidelines are:

1. Section 4.2: To provide reasonable assurance that the most severely degraded tubes are selected, it is recommended that all indications that exceed the screening criteria for each degradation mechanism be in situ tested.
2. Section 5.2.3: The pressurization rate should be less than 200 psi/sec average to each hold point.
3. Section 5.2.5 and 5.2.6: Intermediate pressures should be selected to demonstrate crack stability, since the lowest stable pressure reached without failure is the maximum pressure that can be used to conservatively assess structural integrity.
4. Section 5.2.6: The minimum hold time for proof testing is two minutes.

Finalization of these guidelines in their appropriate documents, which are referenced in NEI 97-06, will occur following the EPRI/SGMP Protocol for guideline development and revision.

No changes are recommended at this time to industry standard analytical modeling methodology for all morphology types. However, it is emphasized in this letter that for the specific morphology of a single, planar, axial, deep part through-wall EDM notch or crack, such as used in the ANO 2 test program, a bounding solution for the deterministic prediction of the burst pressure based on ligament tearing documented in Reference 4, should be used. The solution uses a modification of the Cochet equation and is developed in Reference 3. Alternately, a solution developed by Argonne National Laboratory (see Reference 5) may be used.

The analysis of the data is still not complete and you will be kept informed of the results. For past in situ pressure tests, any tests with hold times at pressure continue to be valid.

Similar guidelines should be considered for laboratory leakage and testing, but final recommendations require approval via the EPRI/SGMP Protocol for guideline development and revision.

EPRI/SGMP requests feedback on problems encountered in implementation of these interim guidelines and unexpected testing results. Please direct feedback to SGMP's Mati Merilo (e-mail: mmerilo@epri.com; telephone: 650-855-2104).

cc Jim Riley, NEI
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